CHAPTER 1

INTRODUCTION

1-1. Purpose

This manual establishes minimum requirements for the process of commissioning mechanical systems supporting major fixed Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance (C4ISR) Facilities. The purpose of this manual is to provide Facility Managers the information necessary to plan for and implement commissioning of mechanical systems. The commissioning process (sometimes referred to as "acceptance testing") includes achieving, verifying, testing, accepting, and documenting that the performance of mechanical systems meets design intent and the owner and occupant needs. Ideally, the process begins at the program phase and lasts at least one year after project-closeout. The commissioning process involves the participation of all parties in the building delivery cycle. At project-closeout, systems needed for immediate operation of the facility have been tested and are considered acceptable. Upon achieving final acceptance at the conclusion of the post acceptance period, the last step of the commissioning process, the owner and/or his operating and maintenance (O & M) contractor take over full ownership and responsibility of the mechanical systems.

1-2. Scope

This manual shall be used for the process of commissioning mechanical systems in C4ISR Facilities. The commissioning process applies to all phases of a facilities life-cycle including program, design, construction, acceptance, post-acceptance phases, and training of O & M staff, and can be applied throughout the life of the building. This technical manual applies to assessment/testing of new construction, i.e., commissioning, reassessment/retesting of existing facilities, or facilities modified or fitted with new equipment, i.e., re-commissioning, and also to assessment/testing of operating facilities which were not commissioned when new, i.e., retro-commissioning. The requirements of this manual are predominantly for testing systems. It is assumed that detailed/comprehensive individual testing of equipment has been completed. The mechanical systems included are for specifically designated fixed ground-based facilities in a threat-hardened C4ISR network.

1.3 References

Required and related publications and prescribed forms are listed in appendix A.

1-4. Objectives

Survivable C4ISR capabilities are essential for a credible military deterrent. This manual supports threat-survivability objectives by providing standardized commissioning and re-commissioning of mechanical systems for support of fixed ground-based facilities in a threat-hardened C4ISR network. These uniform requirements ensure balanced threat hardening for all critical facilities in the network.

1-5. General system testing requirements

The purpose of mechanical systems commissioning is to increase the reliability of mechanical power systems after installation by identifying problems and providing a set of baseline values for comparison with subsequent routine tests. A procedure should be developed to include a planned approach (road map) of what should be done in order to verify the proper system installation. This procedure is the commissioning plan. Specific areas addressed in a commissioning plan include the verification of the installation of all equipment/components, interface connections between equipment and individual systems, and interconnection drawings. The development of this test plan specific to each system and/or component is key to the usefulness of any maintenance program. The plan consists of the schedule of when acceptance and routine tests should be performed, test forms to be used to record the outcome of the tests which are retained for comparison with previous and subsequent tests, and a listing of the required test devices. Since the results of the commissioning tests become baseline test values to compare with later tests and the results of the routine maintenance tests are compiled to identify any downward trend in performance, it is vital to the maintenance program to have accurate and complete records. To perform the testing, the plan lists all required tests in order of performance and gives a schedule for each test. The work items and schedule depend on many items including the importance and cost of the equipment, consequences of failure, age of equipment, past and future frequency of service, hours of operation, future maintenance availability, environmental conditions, and safety requirements.

1-6. Component testing

The reliability of any system is dependent on the interconnection of the equipment and the equipment itself. This manual's purpose is predominately for testing of Mechanical systems themselves. It is assumed that the detailed and comprehensive individual testing of equipment has been completed before the commencing of commissioning of the system. However, general testing procedures for the components of the systems described in this manual are addressed in chapter 3. Commissioning requirements for the system components are typically provided with the original proposal for the procurement of the equipment. The requirements provided by the equipment manufacturer should be adhered to in addition to the recommended testing herein. Although there are many of different components to any mechanical system, there are some tests that are common among the equipment. Examples of the common testing procedures include the assembly check, alignment check, grounding verification, insulation resistance tests and polarization index to name a few. These common tests are described in detail in chapter 2. Sufficient time should be allocated to define the inspections required, perform the check, and document the results. A review of the system drawings will show major pieces of equipment. Specific procedures should be developed for each test referencing the equipment to be used, drawings to be followed, and step by step procedures with readings to be recorded and forms for the results.

1-7. System commissioning testing

Mechanical systems commissioning on new projects is critical to ascertain that a system is installed properly and that it will remain in service for its projected life cycle. The commissioning of a system encompasses the individual testing of the related components, the verification of the component interconnection against the drawings, and the functional testing of the system as a whole. An understanding of the equipment involved and the modes of operation for a system are essential to the development of the system commissioning plan. A survey of the equipment of the system and listing the equipment in order of importance and startup is the first step in developing the commissioning plan. The schedule of the tests and inspections is dependent on many aspects of the equipment such as its importance and cost, the frequency of service, hours of operation, environmental conditions, accessibility, and safety requirements. The inspection, testing, and startup plan is then developed in conjunction with this schedule with instructions and procedures for the test plan. Examples of systems testing are discussed in chapters 4 through 10. DA Forms 7477-R through 7488-R are checklists designed to assist in these inspections and tests. They are found as reproducible forms at the end of this manual. Problems may arise during the testing of the equipment and systems. In order to identify and correct these problems, troubleshooting techniques should be developed. Checking of equipment such as fuses, lights, and breakers for continuity, equipment calibration and settings, and investigating for faulty equipment or connections should be the first troubleshooting steps. For all problems, the equipment and component manuals are consulted for troubleshooting directions. Examples of the possible causes to common problems are shown for each system in the chapters that follow.

1-8. Cost of commissioning

The cost of commissioning for a mechanical system is dependent upon many factors including the system size, complexity and the level of reliability desired. New building construction, renovation of an existing building, or the modernization also will effect the cost of commissioning. Experience has shown that the initial commissioning cost is more than offset by increased system reliability and reduced operating costs. The cost for commissioning a new building can range from 0.5 to 1.5 percent of the total construction cost as shown in the table below. For an existing building the commissioning costs can range from three to five percent of the total operating costs. Commissioning costs and saving are further discussed in chapter 2.

Table 1-1. Costs of commissioning, new construction

Commissioning Scope	**Cost**
Entire building(HVAC, Controls, Electrical, Mechanical) Commissioning	0.5-1.5% of total construction cost
HVAC and Automated Control System Commissioning	1.5-2.5% of mechanical system cost
Electrical Systems Commissioning	1.0-1.5% of electrical system cost
Energy Efficiency Measures Commissioning	$0.23-0.28 per square foot

Source: Portland Energy Conservation Incorporated/Building Commissioning Guide, US Department of Energy, 30 July 1998

1-9. Examples of commissioning

Companies which have said to successfully commission facilities include Westin Hotels and Resorts, the Boeing Company, Wal-Mart, and Target. Descriptive examples of other facilities where the commissioning process was implemented follow.

a. Wedge 1, Pentagon, Washington D.C. The five-story Pentagon building built in 1943 has a gross area of 6,600,000 square feet. The Pentagon, considered a National Historic Landmark, had never undergone a major renovation. Many areas no longer met health, fire, and life safety codes, nor did they provide reliable electrical, air conditioning, and ventilating services. Rented boilers and chillers had to be brought in and connected to the existing utility distribution system for several years, at a cost of about $200,000 a month. As a result of these deficiencies, renovation efforts for the Pentagon were initiated in 1990. The first phase of the renovation program, completed in 1997, included a new heating and refrigeration plant (H&RP) and center courtyard with utility tunnel. The tunnel houses piping and conduit to distribute building utilities provided by the new plant, including new steam, chilled water, natural gas, domestic water, and fire protection lines. The second phase involved the renovation of the basement and mezzanine. The third phase involves renovation of the 1,000,000 square feet of space in Wedge 1 defined as that wedge containing Corridors 3 and 4. Wedges 2 through 5 were scheduled for renovation with renovation of the last wedge, Wedge 5, to be completed in 2014. Due to the events of September 11, 2001, Wedges 1 and 2 received extensive damage. Clean up and reconstruction operations are currently taking place. The completion date, therefore, for renovation of the entire Pentagon is now subject to change.

(1) Renovation of Wedge 1 started with tenants moving out in January 1998. The move-out was completed December 31, 1998. This project involved the complete renovation of Wedge 1, including demolition and reconstruction of all interior spaces, along with mechanical, electrical, and information management and technology (IM&T) systems.

(2) The design phase was complete and construction was just beginning when commissioning activities were initiated. Commissioning included building system design reviews, equipment and product data submittal reviews, reviews of O & M manuals, training plans, equipment startup checklists, functional performance tests, and "as-built" drawings. Commissioning also included execution of equipment startup checklists and functional performance tests.

(3) Commissioning was completed in January 2001, and the grand opening was held on March 8, 2001.

(4) Systems in the scope of the Wedge 1 commissioning effort include: heating, ventilating, and air conditioning (HVAC), energy management control system (EMCS), indoor air quality system (IAQS), natural gas, domestic water, plumbing, lighting, electrical distribution, emergency power, fire/smoke alarm systems, fire/smoke protection systems, kitchen and food preparation systems, flexible ceiling, lighting, partition systems, and vertical transportation systems. The renovation also provides disabled accessibility features, preservation of historic elements, installed modern telecommunications support features, compliance with energy conservation and environmental requirements, and reorganized materials handling and safety improvements in vehicular and pedestrian traffic. IM&T systems, of primary importance in the design and construction in the Pentagon renovation, were commissioned by specialists internal to the Pentagon due to the highly specialized nature of these systems.

(5) Representatives on the Wedge 1 commissioning team included: IM&T, architect/engineer and construction manager (AE/CM), design A/E (DA/E), owner/operator appointed commissioning specialist (CS), general contractor (GC), electrical contractor (EC), EMCS contractor, mechanical contractor (MC), owner's representative (Owner), owner/operator (O/O), and the testing, adjusting, and balancing (TAB) contractor.

(6) The commissioning plan provided for reviews of submittals for: shop drawings and product data, installation and startup instructions, operation and maintenance data, sequences of operation for HVAC, fire protection, kitchen equipment, electrical equipment, emergency generators, uninterruptible power supply, security systems, and the EMCS.

(7) Reviews of procedures and the schedule were required by the commissioning plan. The plan addressed functional performance tests, handling of deficiencies, sampling, failure limits and acceptance criteria, and opposite season testing. Also addressed were training plans, schedule, location, outline,

instructors qualifications, duration, individuals needing to attend, hands on operation, and documentation of training sessions.

(8) No final commissioning report is currently available.

(9) For the remaining wedges, the Pentagon will pursue a different approach to renovation. Instead of the usual design-bid-build approach which requires the Pentagon to develop extensive drawings and specifications and places the Pentagon in between the design firm and the construction contractor during construction, the new approach will be design-build. This will require the design firm, contractor, subcontractors, and the Pentagon to produce a renovated facility with the tenants and owner in mind. This cooperative process is most easily conducted through the commissioning process. Starting with Wedge 2, commissioning will be initiated at the start of the design phase as it has already been implemented in the program phase. The design-build contract will rely on performance specifications. This means firms will be told what the Pentagon wants and how those requirements will be validated, but there will be no specifics on how they should achieve those goals. Design-build firms will be held accountable through a validation process. The marriage uses commissioning to accomplish its objectives. Included are systems manuals, training, testing, verification, documentation, and accessibility and maintainability of the equipment. The Pentagon will also incorporate in the commissioning plan, energy conservation, use of environmentally friendly products, and a wide range of items that impact the environment and human health.

b. Commissioning and re-commissioning of Army HVAC systems. This letter report dated September 30, 1998, presents progress and results from United States Army Construction Engineers Research Laboratories (USACERL) research and development on commissioning and re-commissioning of HVAC systems in Army facilities. This report was prepared by the USACERL in cooperation with HQ FORSCOM, the Public Works Business Center O & M staff, and the local Corps District.

(1) USACERL's research objectives were to evaluate HVAC commissioning efforts by performing condition assessments and reviewing performance data, re-commission problematic systems, develop a standardized commissioning methodology, and develop standardized HVAC commissioning and re-commissioning procedures.

(2) During the summer of 1998 condition assessments were performed on five relatively new buildings totaling 225,000 square feet of space. The condition assessments documented problems and operational deficiencies with HVAC systems. Deficiencies for all five facilities include manual valves installed where automatic valves should be, dampers operating improperly or not at all, automatic control valves manually positioned, systems set to run in manual mode because of difficulty programming the microprocessor or lack of training, systems running full time because of misinformed operations staff, systems running in the wrong mode, systems under-sized, improperly sequenced actuators, improperly activated economizers, improperly tuned controllers, improperly selected and/or installed sensors and transmitters, improperly piped three-way valves, extremely dirty or blocked fan coils, lack of documentation to properly operate and maintain the system, lack of or non-functioning test equipment, and lack of training.

(3) The condition assessments indicated that the commissioning effort would greatly benefit from improved procedures. Most of the identified deficiencies existed when the government took ownership of the facilities. They also indicate that the commissioning effort needs coordination in the design phase, construction phase, and in operation and maintenance.

(4) A "get well plan" for each facility identifying remedies for each deficiency discovered during the condition assessment was prepared and submitted to the maintenance contractors. Many of the problems were corrected during re-commissioning.

(5) Some commissioning problems stem from lack of funds available for commissioning efforts, lack of time, low bid contracts, requirement to develop non-proprietary specifications, lack of control/quality afforded because of design-bid-build contracts, control system complexity, poor coordination, insufficient/understandable and usable documentation, lack of instrumentation and performance verification testing, and lack of follow through and participation.

(6) The report states that USACERL is working with the Louisville District Fort Campbell office and the main Louisville District office to improve the commissioning process. Critical elements to the commissioning process include coordination; use of a commissioning consultant; buildability, constructability, and operability review; streamlining of commissioning requirements; development of a submittal register; submittal review; construction inspections; and functional performance testing. Problems faced by construction, and O & M contractors participating in commissioning efforts include staff reductions, inadequate funds, complex technologies, and lack of training.

(7) General conclusions on commissioning costs were made. No specifics were given as there are no established methods for determining costs or savings. The report stated that it appears that the cost of commissioning/re-commissioning is too high for economic justification. Other avenues such as energy savings performance contracts (ESPC) are becoming a popular mechanism for funding deferred maintenance projects. However, the concern for accurate measurement and verification of energy savings exists.

(8) The report concluded that HVAC projects would benefit from an independent commissioning/re-commissioning consultant as in-house resources and expertise are lacking; re-commissioning should be accomplished with repairs that require low to no maintenance, and proper maintenance of systems over the life of a facility is key for energy efficiency and effective operation.

(9) Recommendations for future consideration include implementing commissioning in future projects, coordinating work with the United States Air Force (USAF), review and revision to guide specifications to include performance verification testing, using a commissioning consultant, training on commissioning of HVAC systems, developing an O & M PROSPECT (proponent sponsored engineer corps training) course, developing ways to evaluate energy loads and usage, and review of American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc. (ASHRAE) commissioning guidelines. Also recommended were developing comprehensive condition assessment techniques from procedures to required instrumentation and documentation, developing ways to contract these assessments, training engineers to conduct assessments, developing energy saving computations, developing techniques to monitor ESPCs, and a simplified commissioning/re-commissioning process. The simplified process would include a set of streamlined, low-tech, and simple HVAC control strategies and specifications that are easy to design, install, commission, operate and maintain. The strategies and hardware should be low cost, low maintenance, and include elements of standardization.

c. Fort Myer, Virginia, commissary. The measured system performance and diagnostic testing report for the Fort Myer, Virginia, commissary was prepared for the Defense Commissary Agency (DeCA), Directorate of Facilities, Facilities and Programs Division, Fort Lee, Virginia, by the USACERL in Champaign, Illinois, in 1997.

(1) The purpose of this study was to identify deficiencies in the operation of energy systems within the commissary. The overall goal of this work was to investigate methods for more efficient design and operation of DeCA facilities.

(2) Diagnostic testing of energy systems at the Fort Myer commissary was conducted from September 1996 through July 1997. Activities included meeting with the maintenance contractor, reviewing system design, assessing equipment condition, walking through the facility, reviewing the metering plan, collecting data using dataloggers, review and repair of equipment, performance verification testing (PVT), single-point measurement testing, installation of a kWh pulse meter, repair of a facility power meter, and checkup visits for operational review of the refrigerant management and control system (RMCS).

(3) Systems and equipment investigated include the chilled water system (CHWS), hot water system, refrigeration system, main store air handling system, administrative zone air handling unit, metering, lighting, ventilation, and domestic hot water system.

(4) Throughout the fall of 1996, the maintenance contractor was notified of various findings, and corrections or explanations were provided. The period from January to July was used to provide periodic checks on overall store operation and to analyze data collected. Of interest throughout this procedure was to see how operation of the commissary changed with seasonal weather changes.

(5) There were two major design-related deficiencies that appear to be systemic with other commissaries and should be looked into further by DeCA. The first is the use of a single packaged chiller to supply cooling to various zones with different thermal requirements. The second deficiency involves the need for manually setting up the automated store systems before each season. The match of equipment and HVAC control systems does not allow for year-around automation without some operator, maintenance contractor intervention. This can be a costly way to operate a store.

(6) There are two other design aspects which the study recommends be investigated by DeCA. The first is the continued use of supply air rates equal to about 1 cfm per square feet of floor area. This rule-of-thumb for store design is being scaled down to 0.5 cfm or less in light of better design methods. The second is the improper specification and subsequent operation of desiccant or other forms of dehumidification equipment.

(7) Numerous small deficiencies were identified and either corrected on-site or reported to the contractor and fixed through the maintenance program. Other findings and deficiencies lead to the following recommendations.

(a) Reinstate automated seasonal operation control changes.

(b) Adjust main air handler valve sequencing.

(c) Repair, calibrate, and tune as necessary HVAC sensors and rack discharge head pressure sensors.

(d) Repair rack defrost temperature termination problems.

(e) Repair and reinstate the night setback timeclock for the admin zone.

(f) Repair the ventilation air problem in the administrative offices.

(g) Obtain and file manuals and drawings for equipment in the mechanical room.

(h) Investigate store zone temperature inconsistencies.

(i) Investigate the Liebert unit used to condition single office.

(8) The results of the study were quite favorable. Aside from a few apparent problems at the onset of the study, the commissary appears to be running rather efficiently. A number of deficiencies (mostly minor) were identified throughout the procedure. Any mission-critical problems (such as equipment malfunctions) and some other operational deficiencies were repaired at the time of malfunction.

(9) This report suggests that an economic analysis of the impact of the recommended repairs and improvements would require the use of simulation tools. However, simulations are known to fall short when trying to model the actual behavior of mechanical systems. Most changes suggested by the report are said to be extremely cost-effective, and are warranted for comfort, productivity, or operation and maintenance projects. No costs or savings were provided.

(10) The report recommends that the DeCA HQ, store personnel, maintenance contractor, and the USACERL jointly determine the appropriate scope for the re-commissioning effort. Operation of systems often reverts back to an inefficient or dysfunctional state if the agreed upon objectives of these organizations are not clear, understood, and implemented. Experience with successful re-commissioning and subsequent implementation of energy conservation opportunity (ECO) projects dictates that the following recommendations be implemented.

(a) Maintain up-to-date working descriptions and schematics of all equipment and systems.

(b) Maintain an up-to-date working sequence of operation.

(c) Maintain a current directory of vendor telephone numbers for technical support.

(d) Complete deficiency action items agreed upon in the scope.

(e) Verify working systems, including data collection and trend analysis plots.

(f) Provide on-site training to store and maintenance personnel using the actual equipment in the building.

(g) Use the advice from manufacturers field support, particularly with regard to HVAC and controls equipment.

(h) Maintain equipment maintenance logs to help alleviate problems.

(i) Investigate an automated contract maintenance system as these systems have been shown to dramatically improve the ability of maintenance managers and field personnel to diagnose and solve problems.

(j) Provide feedback of system operation to maintenance personnel.

d. USAF Academy, Colorado, commissary. The measured system performance and diagnostic testing report for the USAF Academy commissary in Colorado was prepared for the DeCA, Directorate of Facilities and Programs Division, Fort Lee, Virginia, by the USACERL in Champaign, Illinois, in 1994.

(1) The USAF Academy commissary was designed in FY 1990, built in FY 1992, and opened for business in August 1992. Weather at the USAF Academy presents a design and operational challenge. The high-altitude location and highly variable nature of weather provide daily temperature differences in excess of 80°F. The facility totals 63,300 square feet.

(2) The purpose of the re-commissioning effort was to determine cost savings by identifying problems with the design, construction, operation, and maintenance of the facility as it currently exists. The goal was to provide a building owner and operating staff an efficient, cost-effective, healthy, and productive environment, and to provide feedback to designers on what aspects of their designs do and do not work in the field.

(3) A system metering and component testing plan was developed to provide information on the major energy consuming systems and components. Data was collected throughout the facility for a 21-day period beginning midnight June 7, 1996. Systems/equipment/conditions investigated include packaged chiller CH-1; chilled water pumps and distribution; packaged hot water boilers B1 and B2; hot water pumps and distribution; main air handling/desiccant unit DD-1; administrative area air handling unit (AHU) AHU-2; refrigeration compressor racks 1 through 4 (R1-4); electric defrost racks 1, 2, and 3; store ambient conditions - dry grocery/checkout; store ambient conditions - cold aisles; rooftop weather station; lighting system; HVAC subsystem; and the battery charging system.

(4) Numerous small deficiencies were identified and either corrected on-site or fixed through the maintenance program. A significant problem with excessive compressor cycling, due to oversizing of the packaged chiller was reported. The following summarizes the most substantive recommendations and deficiencies that need to be implemented or addressed as the related deficiencies were not corrected by USACERL during the investigation.

(a) The oversized chiller needs to be addressed.

(b) The costly desiccant dryer system is not warranted.

(c) Part load operational control needs to be provided for boilers.

(d) The oversized main store supply air flow needs to be addressed.

(e) Continuous operation of supply fan in the admin zone needs to be addressed.

(f) The CHWS pump needs to be downsized or the impeller trimmed.

(g) Night setback needs to be reinstated.

(h) Heat reclaim needs to be reinstated.

(i) Store light levels need to be reduced during off hours.

(j) The humidistat needs to be recalibrated and the relative humidity setpoint lowered.

(k) The controller deadband for heating and cooling of zone DD-1 needs to be increased.

(l) Operation of mezzanine exhaust fan (EF-8) needs to be reinstated.

(m) The control system needs to be set to monitor daily cycles of the refrigerant compressor.

(n) Reactivate controls to shut off case lights during unoccupied hours.

(o) Disconnect anti-sweat heaters.

(p) Implement lead/lag strategy for boilers.

(q) Correct fan sequence logic on desiccant unit.

(r) Correct the condensate leak at boiler B-2 exhaust.

(s) The fire damper actuator and performance verification testing (PVT) fire suppression system need repair.

(t) Negotiate lower flat-rate electricity charge.

(u) Investigate economizer operation and implement economizer control.

(v) Consider installing a dedicated rooftop direct expansion (DX) unit for AH-2.

(w) Get chilled water under on/off control by implementing outside air lockout.

(x) Downsize chilled water pumps on package chiller.

(y) Get boilers under on/off control by implementing outside air lockout.

(z) Implement hot water reset strategy to save heating energy.

(aa) Trim impellers on HWS to match maximum load requirement.

(bb) Set control system to monitor compressor daily cycles.

(cc) Investigate circuits 10 and 14 for problems relating to excessive sources of moisture at or near the load.

(5) This report suggests that an economic analysis of the impact of the recommended repairs and improvements would require the use of simulation tools. However, simulations are known to fall short when trying to model the actual behavior of mechanical systems. Most changes suggested by the report are said to be extremely cost-effective, and are warranted for comfort, productivity, or operation and maintenance projects. No costs or savings were provided.

(6) The report recommends that the DeCA HQ, store personnel, maintenance contractor, and the USACERL jointly determine the appropriate scope for the re-commissioning effort. Operation of systems are often inefficient or dysfunctional if the objectives of these organizations are not clear, understood, and implemented. Experience with successful re-commissioning and subsequent implementation of ECO projects dictates that the following recommendations be implemented.

(a) Maintain an up-to-date working description and schematics of all equipment and systems.

(b) Maintain an up-to-date working sequence of operation.

(c) Maintain a current directory of vendor telephone numbers for technical support.

(d) Complete deficiency action items agreed upon in the scope.

(e) Verify working systems, including data collection and trend analysis plots.

(f) Provide on-site training to store and maintenance personnel using the actual equipment in the building.

(g) Use the advice from manufacturers' field support, particularly with regard to HVAC and controls equipment.

(h) Maintain equipment maintenance logs to help alleviate problems.

(i) Investigate an automated contract maintenance system as these systems have been shown to dramatically improve the ability of maintenance managers and field personnel to diagnose and solve problems.

(j) Provide feedback of system operation to maintenance personnel.

e. Antilles High School, Fort Buchanan, Puerto Rico. A condition assessment of the HVAC system in the Fort Buchanan, Puerto Rico, Antilles High School, was conducted in June 1999. This effort was done prior to possible retro-commissioning of HVAC systems. There are 12 air handling units and 3 compressed air stations in the school. Following is a summary and recommendations from this assessment.

(1) The HVAC equipment was well-designed and is appropriate for the intended application. The equipment was appropriately sized to handle the cooling loads. Equipment condition, however, is significantly degraded, especially the controllers and actuators. All of the HVAC controls are pneumatic and have failed. Air compressors were inoperable, pneumatic lines are fouled and plugged, and the majority of actuators had broken or disconnected linkages. At best the system is manually controlled and operated in an on-off mode.

(2) An existing proposal to replace the Antilles High School HVAC control system was also reviewed. The proposal was thorough in the type of controls to be replaced, but did not include the need to replace pneumatically-actuated equipment.

(3) Recommendations from the assessment include replacement of the entire pneumatic control system with a new direct digital control (DDC) system; replacement of sensors, valves, inlet guide vanes, dampers, and blowers; and replacement of actuated devices on control valves and inlet guide vanes with electric actuators. The new system needs to insure compatibility with existing maintenance practices; insure that all necessary DDC functions such as energy management, reporting, alarming, diagnostics, and remote operating capability are included; and account for future network expansion to other DoDEA schools in Puerto Rico. It was also recommended that DoDEA consider developing a DDC-based HVAC controls specification for use at other DoDEA facilities.

f. Army Buildings, Fort Bragg, North Carolina. The HVAC systems in two company administrative and supply buildings were retro-commissioned in December 1998. Retro-commissioning methodology development and quantification of benefits and costs was prepared for the Construction Engineering Research Lab, by the Architectural Engineering Department NC A&T State University, Greensboro, NC.

(1) The heating and air-conditioning systems in the two company administrative and supply buildings at Ft. Bragg were inspected and monitored for energy use and environmental comfort. The HVAC systems in the two identical buildings, 6612 and 6715, were inspected and found to be operational, but the temperature control and energy management systems in both buildings were inoperative. The HVAC systems were set to operate 24 hours per day, seven days per week in a full cooling mode. Temperatures in the administrative areas varied widely from morning to evening throughout the year. Doors were opened to the outside in non-conditioned parts of the buildings to adjust for the administrative area temperature. In addition portable heaters were used.

(2) Because of cost constraints, partial retro-commissioning was initiated and included refurbishment of the temperature control systems in Building 6715. Thermostats were replaced, inoperative hot deck and cold deck discriminator controllers were removed, and repair was made to a major air leak in the ductwork of one AHU. The inoperative energy management system was abandoned in place as a cost saving measure and a 24-hour time clock on each of the four AHUs was installed. The time clocks shut down chilled water flow from 6:00 pm to 6:00 am.

(3) Office temperatures and humidity were monitored before and after repairs and retro-commissioning of Building 6715. Ironically, even though the building occupants were advised that the air-conditioning system had been repaired and that temperatures could be controlled via the thermostats, the old habits of opening the front doors and the use of electric heaters continued. A formalized program of occupant training was recommended to correct this habit.

(4) The annual cost of air-conditioning each building was calculated to be $5,000 and retro-commissioning was estimated to save $1,500. If the figures for the heating season were included, the combined savings per building were estimated to be $2,500 per year. The estimated cost of retro-commissioning the buildings was $2,500 per building to replace only defective components, $4,000 per building if all new thermostats are installed, and $25,000 per building if the existing control system is replaced with a state-of-the-art electronic system. The associated simple paybacks are: 1.0 years; 1.6 years; and 10 years, respectively.

g. Aster Publishing Building, Eugene, Oregon. In 1994, the Aster Publishing Company (A.P.C., Inc.) upgraded the HVAC system in their 66,300 square foot office building. This retro-commissioning effort included upgrading the EMCS, lighting controls, variable frequency drives, air handlers, duct structures, and economizers in their 11-year-old headquarters building. A.P.C., Inc., wanted to ensure that their new systems performed well and resulted in occupant comfort and energy savings, and had the support of the water and electric board. Retro-commissioning began during the design phase and continued beyond the construction phase. Major deficiencies identified included excessive infiltration in the return air plenum and a failure of the existing controls to perform consistent with the original design's control strategy. Retro-commissioning was included in the scope of the project and was bid as part of the total project package. Retro-commissioning was performed by the GC/designer. Savings are approximately $40,000 annually in electric. In addition, the company believes the retro-commissioning project resulted in improved temperature control, improved air balance, reduction in tenant complaints, extended equipment life, and fewer equipment failures.

h. Oregon State University Library, Corvallis, Oregon. Oregon State University began the commissioning of its new 336,000 square foot library in 1995. The university wanted to ensure that the systems in the new building promote energy savings and ensure thermal comfort. The HVAC system included an EMCS, variable frequency drives, economizers, and air handlers. Commissioning was incorporated into the project specifications, which outlined commissioning responsibilities of the architect, the mechanical engineer, and the commissioning agent. The estimated cost of commissioning the library was $335,000, or 1 percent of the total construction cost. Expectations from the commissioning effort include energy savings, improved temperature and relative humidity control, improved air balance, improved indoor air quality, and reduced occupant complaints. Also expected were fewer change orders. Commissioning, at the time of this article, had provided noticeable improved communication between the design team and the building operating staff.

i. Local Government Center, Salem, Oregon. The Local Government Center in Salem is a new 40,000 square foot office building. Commissioning was performed with a focus on reduced installation problems, energy efficiency, efficient operation, and maintenance training. Some of the deficiencies identified during commissioning included high carbon dioxide levels, air balance problems, wiring problems, intake of fireplace smoke from adjacent buildings, and inaccurate as-built documents. Noticeable are several non-energy benefits resulting from the commissioning process, including the following.

(1) Numerous construction-related HVAC system problems were discovered and corrected at contractor expense.

(2) Outside air quantities, air temperatures, and carbon dioxide levels were documented.

(3) Operating staff received additional training.

(4) Construction and design teams were more diligent in carrying out their responsibilities because of the involvement of a third-party commissioning agent.

j. Highrise Office Building, Portland, Oregon. In 1995 an 18 year-old downtown 278,000 square foot office building was retro-commissioned by the city of Portland to obtain optimized performance, low-cost operation, and maintenance improvement. Involved were the building's duct heaters, chiller system, EMCS, lighting controls, and air handlers. Retro-commissioning costs and savings were low. The retro-commissioning effort cost $12,700 and included the commissioning agent fee, the cost to pre- and post-monitor equipment to document commissioning savings, and the cost to repair deficiencies. Annual energy savings is $8,145. Staff found improved building temperature control and thermal comfort. In addition O & M documentation available for troubleshooting also was improved by the retro-commissioning effort. Major deficiencies identified include the following.

(1) Electric reheat scheduling and setpoint problems.

(2) Chilled water setpoint temperature set too low.

(3) Space sensors out of calibration.

(4) Chiller short-cycling due to improper time delay setting.

k. Disney World, Orlando, Florida. During its expansion in the 1980s, Disney World experienced numerous building failures, costing $10 million or more over three years. When the company built its new $22 million Vero Beach Vacation Club Resort, it incorporated commissioning during the construction process to ensure the facility worked according to design. The cost of commissioning was $25,000, and construction cost savings exceeded $300,000.

l. Texas Capitol Extension Building. The Texas Capitol Extension Building was designed to be the most energy-efficient state-owned office building. When the building was only a few years old it was re-commissioning. As a result, energy use was reduced by 27 percent or about $145,000 a year. The simple payback for this re-commissioning was three months.

m. State Police Headquarters, Central Point, Oregon. The Oregon Department of Administrative Services (DAS) has 24 state buildings totaling 3.5 million square feet. The DAS is well aware of the time and money required to keep buildings working and people safe and comfortable when building systems are not installed correctly during construction. The new State Police Headquarters in Central Point, Oregon, is a 20,000 square foot facility. It houses a forensic lab and offices and a 5,000 square foot support services building that includes an autopsy suite, vehicle lab, gun testing room, drying room, and freezers. The commissioning process for the State Police buildings began at the construction phase. Commissioning was performed by O & M staff instead of a commissioning service provider. Even with these shortcomings, the commissioning effort revealed significant deficiencies before they caused heating and cooling systems to fail, exposing workers to unsafe air quality. This prevented endless comfort complaints and finger-pointing, and wasting of $6,500 worth of energy a year. In the future, the state plans on implementing commissioning from the start in the program phase. Deficiencies identified and repaired include the following.

(1) Drip legs missing for natural gas lines.

(2) Control wires rubbing against sheet metal edges in rooftop package units.

(3) An improperly specified and installed boiler expansion tank.

(4) Boiler exhaust drawn into fresh air intakes on roof.

(5) Improperly installed temperature sensors.

(6) Lab fume hoods not modified to variable-volume.

(7) Hoods and exhaust ductwork left unsealed.

(8) Autopsy and evidence drying room exhaust drawn back inside through fresh air intakes.

(9) Insufficient cooling for autopsy room.